Dynamics of wave packets in two-component BEC under the oscillating external field

Department of Applied Physics,Osaka City University
H.Sakaguchi [1] , H.Yamasaki and K.Nakamura

最近、２成分 BEC の波束のダイナミクスにおいて、ドメイン構造と呼ばれる互いの波束が入れ子状態になる現象が実験と理論の両面から発見された。しかしながらこれらの系では、２成分間で占拠数に移動はない。一方、振動外場のもとでの２準位系のダイナミクスはラビ振動 (占拠数の周期的時間変化) を示す。我々は振動外場を加え、占拠数の移動を誘起して２成分 BEC の波束にダイナミクスを考察する。特に、２成分間での波束の生成及び消滅、ドメイン構造の振動などラビ振動の新たな側面を明らかにする。

Recently, alternately aligned domain structures have been found both experimentally and theoretically in the dynamics of wave packets in two-component BEC. In those systems, however, no population mixing between two componets has been incorporated. On the other hand, Rabi oscillation (population mixing) occurs in two-level systems under the oscillating external field. We investigate the dynamics of wave packets in two-component BEC under the oscillating external field that leads to the population mixing. We shall elucidate a new aspect of Rabi oscillation(space-and time-dependent complex structures) that is generated through the creation and annihilation of wave packets between two components.

We consider the case where there is the oscillating external field coupling between two states (components, $|1>$ and $|2>$) in spatial two dimensions with normalization $N_1 + N_2 = \int (|\psi_1|^2 + |\psi_2|^2) d^2r = 1$. We assume that only one state, $|1>$ is populated initially, and that initial state is a Gaussian wavepacket $\psi_1(r; t = 0) = \frac{1}{\sqrt{\pi}} \exp(-\frac{1}{2}(x^2 + y^2))$ confined to one harmonic trap (see Fig.1). Then, GP equation describing this coupled two-component system is

$$i\hbar \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} = \begin{pmatrix} H_1 + H_1^{MF}, & E\cos(\omega t) \\ E\cos(\omega t), & H_2 + H_2^{MF} \end{pmatrix} \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix} \qquad (1)$$

where,
$H_i = -\frac{\hbar^2}{2m} \nabla^2 + U_i(r)$
$U_i(r) = \frac{1}{2}(x^2 + y^2) + \frac{1}{2}\Delta(-1)^i$: harmonic trap
$H_i^{MF} = g_i|\psi_i|^2 + g_{ij}|\psi_j|^2$: mean-field interaction strength $(i, j = 1, 2; i \neq j)$

First, we show temporal behavior of ψ_1 in Fig.2. During one period ($t = T = 2\pi/\omega$), the wavepacket for ψ_1 recovers after once it disappeared, but its shape has been deformed. What's happened ? To understand this phenomenon , one sees Fig.3 (time evolution of both ψ_1 and ψ_2) : there is a growth of ψ_2 component which compensates the decay of ψ_1 component. That is, there is population mixing between two components leading to the transfer of the wave packet from lower to upper levels and vise versa. Next, the probability amplitude of ψ_1 and ψ_2 is shown in Fig.4(a) and Fig.4(b) in the case of the

[1] E-mail: sakkun@a-phys.eng.osaka-cu.ac.jp

resonance (! = ¢) and non-resonance (! = ¢), respectively. At resonance, we can observe the complete population mixing like Rabi oscillation but the temporal behavior is chaotic. On the other hand, at non-resonance, there appear, a small population mixing and quasi-regular oscillation.

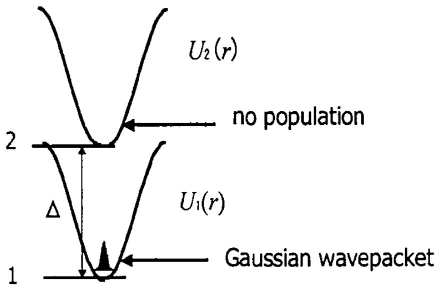

Figure 1: The initial system with only one state populated.

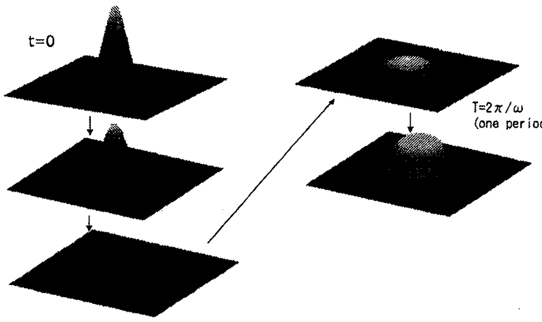

Figure 2: Temporal behavior of $\tilde{A}_1$

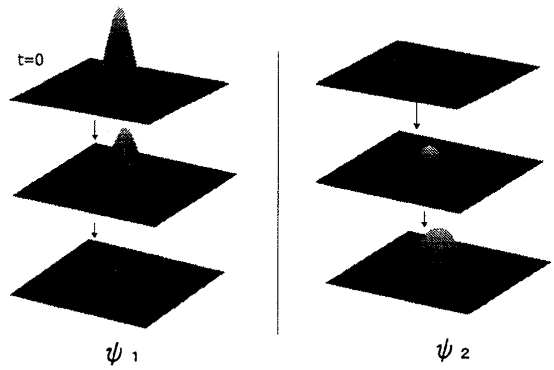

Figure 3: Comparison of time evolution of both $\tilde{A}_1$ and $\tilde{A}_2$

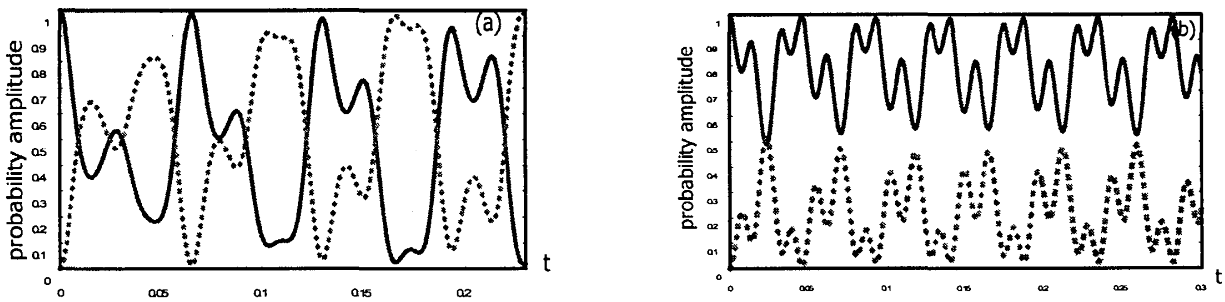

Figure 4: Time evolution of the probability amplitude for $\tilde{A}_1$(solid line)and $\tilde{A}_2$(dotted line): (a)at resonance (! = ¢); (b)at non-resonance(! = ¢).

References

[1] M.Jona-Lasinio, O.Morsch et al., Phys. Rev.Lett. 91 230406 (2003)

[2] A. Smerzi et al., Phys. Rev.Lett. 79 4950 (1997)